## EASTER VACATION WORK AT PORT ERIN.

THE Easter vacation party at the Port Erin Biological Station has this year been larger than ever before, and has carried out a longer programme of work—both in the laboratory and on the seashore. During the last few weeks (March and April) the number of researchers and senior students enrolled in the books of the station has reached the record total of eighty-five, including half a dozen professors and a dozen university lecturers and demonstrators, while nearly half of the total number were post-graduate researchers. Altogether twelve universities or university colleges have been represented. Practically all the senior students and post-graduate workers of the botanical and zoological departments of the University of Liverpool, under Profs. Harvey Gibson and Herdman, migrated to the Port Erin laboratory for the vacation. Prof. Cole brought a considerable contingent from the University College of Reading, and Dr. Stuart Thomson a number from Manchester; Mr. Holden came with some students from University College, Nottingham, and smaller groups came from Birmingham, Cambridge, Oxford, Bristol, Bangor, Cardiff, London, and Melbourne. In addition to the laboratory work of the students and their collecting expeditions on the seashore, the activities of the biological station at this time of year are threefold: first, the flat-fish hatching (seen at its best during March and April); secondly, the plankton investigation going on at sea from the s.y. *Runa*; and thirdly, the special investigations of the post-graduate researchers.

The spawning of the mature plaice in the open-air fish-ponds started at the beginning of February this year, at least a fortnight earlier than usual, and it is by no means finished yet. Already more than eight millions of eggs have been skimmed from the ponds, and about seven millions of young fish have been set free in the sea round the south end of the Isle of Man.

Work at sea was much hampered by bad weather during the earlier part of the time, and it was sometimes difficult to get the periodic plankton hauls taken. This is now the eighth year of Prof. Herdman's scheme of intensive study of the nature and distribution of the plankton, of which it is hoped to complete ten years' statistics before winding up the investigation. Up to the present the phytoplankton this spring has been characterised by the prevalence of Coscinodiscus.

In addition to the collecting and recording of rare species, both of animals and sea-weeds, which has gone on very much as in former years, there has been a large amount of special investigation both at sea and in the laboratory on the part of those who are engaged in the preparation of L.M.B.C. Memoirs, and also of others who are at various researches. For example, Mr. R. D. Laurie has been making observations on the movements of Amphidinium in the sand, Mr. S. T. Burfield has been working at Sagitta, Miss Gleave at Archidoris, Mr. H. G. Jackson on Decapod larvæ in the plankton, and Prof. B. Moore and Mr. E. Whitley on the nutrition of marine animals and the variations in the alkalinity of the sea-water. The memoir on Echinoderm larvæ which Mr. Chadwick has been engaged on for some years is now in the printer's hands, and will be published at an early date. The pressure on the laboratory accommodation has been very great during this vacation, and the need of further extension of the building is urgent.

W. A. H.

---

## RELATIONS BETWEEN THE SPECTRA AND OTHER CHARACTERISTICS OF THE STARS. *

### I.

### *Historical.*

INVESTIGATIONS into the nature of the stars must necessarily be very largely based upon the average characteristics of groups of stars selected in various ways—as by brightness, proper motion, and the like. The publication within the last few years of a great wealth of accumulated observational material makes the compilation of such data an easy process; but some methods of grouping appear to bring out much more definite and interesting relations than others, and, of all the principles of division, that which separates the stars according to their spectral types has revealed the most remarkable differences, and those which most stimulate attempts at a theoretical explanation.

In the present discussion, I shall attempt to review very rapidly the principal results reached by other investigators, and shall then ask your indulgence for an account of certain researches in which I have been engaged during the past few years.

Thanks to the possibility of obtaining with the objective prism photographs of the spectra of hundreds of stars on a single plate, the number of stars the spectra of which have been observed and classified now exceeds one hundred thousand, and probably as many more are within the reach of existing instruments. The vast majority of these spectra show only dark lines, indicating that absorption in the outer and least dense layers of the stellar atmospheres is the main cause of their production. Even if we could not identify a single line as arising from some known constituent of these atmospheres, we could nevertheless draw from a study of the spectra, considered merely as line-patterns, a conclusion of fundamental importance.

The spectra of the stars show remarkably few radical differences in type. More than 99 per cent. of them fall into one or other of the six great groups which, during the classic work of the Harvard College Observatory, were recognised as of fundamental importance, and received as designations, by the process of "survival of the fittest," the rather arbitrary series of letters B, A, F, G, K, and M. That there should be so few types is noteworthy; but much more remarkable is the fact that they form a continuous series. Every degree of gradation, for example, between the typical spectra denoted by B and A may be found in different stars, and the same is true to the end of the series, a fact recognised in the familiar decimal classification, in which B5, for example, denotes a spectrum half-way between the typical examples of B and A. This series is not merely continuous; it is *linear*. There exist indeed slight differences between the spectra of different stars of the same spectral class, such as AO; but these relate to minor details, which usually require a trained eye for their detection, while the difference between successive classes, such as A and F, are conspicuous to the novice. Almost all the stars of the small outstanding minority fall into three other classes, denoted by the letters O, N, and R. Of these O undoubtedly precedes B at the head of the series, while R and N, which grade into one another, come probably at its other end, though in this case the transition stages, if they exist, are not yet clearly worked out.

From these facts it may be concluded that the principal differences in stellar spectra, however they may originate, arise in the main from variations in a single physical condition in the stellar atmospheres. This follows at once from the linearity of the series. If the spectra depended, to a comparable degree, on two independently variable conditions, we should expect that we would be obliged to represent their relations, not by points on a line, but by points scattered over an area. The minor differences which are usually described as "peculiarities" may well represent the effects of other physical conditions than the controlling one.

---

* An address delivered before a joint meeting of the Astronomical and Astrophysical Society of America and Section A of the American Association for the Advancement of Science, at Atlanta, Georgia, December 30, 1913, with a few additions, by Prof. H. N. Russell.

The first great problem of stellar spectroscopy is the identification of this predominant cause of the spectral differences. The hypothesis which suggested itself immediately upon the first studies of stellar spectra was that the differences arose from variations in the chemical composition of the stars. Our knowledge of this composition is now very extensive. Almost every line in the spectra of all the principal classes can be produced in the laboratory, and the evidence so secured regarding the uniformity of nature is probably the most impressive in existence. The lines of certain elements are indeed characteristic of particular spectral classes; those of helium, for instance, appear only in Class B, and form its most distinctive characteristic. But negative conclusions are proverbially unsafe. The integrated spectrum of the sun shows no evidence whatever of helium, but in that of the chromosphere it is exceedingly conspicuous. Were it not for the fact that we are near this one star of Class G, and can study it in detail, we might have erroneously concluded that helium was confined to the "helium stars." There are other cogent arguments against this hypothesis. For example, the members of a star-cluster, which are all moving together, and presumably have a common origin, and even the physically connected components of many double stars, may have spectra of very different types, and it is very hard to see how, in such a case, all the helium and most of the hydrogen could have collected in one star, and practically all the metals in the other. A further argument—and to the speaker a very convincing one—is that it is almost unbelievable that differences of chemical composition should reduce to a function of a single variable, and give rise to the observed linear series of spectral types.

I need not detain you with the recital of the steps by which astrophysicists have become generally convinced that the main cause of the differences of the spectral classes is difference of temperature of the stellar atmospheres. There is time only to review some of the most important evidence which, converging from several quarters, affords apparently a secure basis for this belief.

The first argument is based upon the behaviour of the spectral lines themselves. To appreciate its full force, one must familiarise himself with a multitude of details. A typical instance is that of the heavy bands in the region of longer wave-length, which are the most characteristic feature of spectra of Class M, appear faintly in Class K5, and are absent in Class K and all those higher in the series. Fowler has shown [1] that these bands are perfectly reproduced in the spectrum of the outer flame of an electric arc charged with some compound of titanium, while the spectrum of the core of the arc, though showing conspicuously the bright lines of titanium, does not contain the bands. Here we are evidently dealing with some compound—perhaps titanium oxide—the vapour of which is present in the relatively cool flame of the arc, and emits a spectrum of the banded type, characteristic of compounds, while in the hotter core it is dissociated, and only the lines of the metal are seen. There seems then to be no escape from the conclusion that the atmospheres of stars of Class M are cool enough to permit the existence of this compound, and hence cooler than the core of the arc, and that the temperature of its dissociation is approached in Class K5, and surpassed in Class K. In general, those metallic lines which are relatively strong in the spectra produced in the oxyhydrogen flame or the electric furnace are also strong in spectra of Classes M and K; the lines most prominent in Class G are the typical arc lines; and the relatively few metallic lines which persist into Classes A and B are those which appear exclusively, or with greatly enhanced intensity, in the spark spectra of the laboratory.

The second line of evidence is afforded by the distribution of intensity in the continuous background of the spectra, the differences of which from type to type are obvious to the eye as differences in the colour of the stars. This characteristic is fortunately capable of accurate measurement. For the brighter stars, spectro-photometric comparisons may be made with a terrestrial light-source the energy curve of which is known, as has been done visually by Wilsing and Scheiner,[2] and photographically by Rosenberg.[3] Much fainter stars may be reached by the comparison of their brightness as measured visually (or on isochromatic plates with a suitable colour-screen), and photographically on ordinary plates. The "colour-index" so obtained, which expresses, in stellar magnitudes, the relative photographic brightness of stars of equal visual brightness, is found to be very intimately related to the spectral type, the differences within each spectral class being scarcely greater than the errors of observation. The results of King,[4] Parkhurst,[5] and Schwarzschild,[6] working with different instruments and on stars of very different brightness, are in excellent agreement, as is shown in Table I. The near approach to equality among the differences in colour-index from class to class is very remarkable, when it is considered that these types were picked out somewhat arbitrarily according to the general appearance of the photographic spectra. The judgment of the Harvard observers in selecting the really important points of difference was evidently very good.

Table I.

| Spectrum | Colour-index | | | Temperature |
|---|---|---|---|---|
| | King | Parkhurst | Schwarzschild | ° |
| Bo | −0·32 | | | 20,000 |
| B5 | −0·17 | −0·21 | −0·20 | 14,000 |
| Ao | 0·00 | 0·00 | 0·00 | 11,000 |
| A5 | 0·19 | 0·23 | 0·20 | 9,000 |
| Fo | 0·30 | 0·43 | 0·40 | 7,500 |
| F5 | 0·42 | 0·65 | 0·60 | 6,000 |
| Go | 0·72 | 0·86 | 0·84 | 5,000 |
| G5 | 0·98 | 1·07 | 1·10 | 4,500 |
| Ko | 1·10 | 1·30 | 1·35 | 4,200 |
| K5 | 1·62 | 1·51 | 1·80 | 3.200 |
| M | 1·62 | 1·68 | | 3,100 |
| N | | 2·5 | | 2,300 |

If the spectral sensitiveness of the plates used in such investigations has been determined (as Parkhurst has done) it is possible to calculate the temperature at which a black-body would emit light of the same colour as that observed; and similar calculations can be made, with greater accuracy, from the spectrophotometric data. The last column of Table I. gives the effective temperatures thus derived (based mainly on the work of Wilsing and Scheiner). The absolute values of the temperatures here given may be considerably in error, especially at the top of the scale (in fact, Rosenberg's work indicates a much greater range), but there can be no doubt about the relative order.

---

[1] Proc. Roy. Soc., vol. lxxii., pp. 219–225, 1904.

[2] Potsdam Publications, vol. xix., part 1.

[3] *A.N.*, 4628, 1913.

[4] Harvard Annals, vol. lix., p. 179.

[5] *Astrophys. Jour.*, vol. xxxvi., p. 218, 1912.

[6] Göttingen Aktinometrie, Teil B, p. 19.

Of a third independent confirmation of the temperature hypothesis, based on the determination of the surface brightness of the stars, I shall have occasion to speak later.

It should be expressly stated that the "temperatures" here spoken of are the effective "black-body" temperatures corresponding to the spectral distribution of the radiation. Unless the surfaces of the stars possess decided selective emissivity for certain wavelengths, these effective temperatures should also indicate with tolerable accuracy the energy-density of the flux of radiation which escapes from them. This tells us little about the temperature of the deeper regions; but it must be the main, if not the only, factor in determining the temperature of those outer and nearly transparent layers of the atmospheres in which the characteristic line absorption takes place. If we further assume, in accordance with Abbot's studies of the solar atmosphere,[7] that the absorption is nearly complete in so small a thickness of the atmosphere that wide variations in its depth and density would modify its total absorption but little, it becomes easy to see how the influence of its temperature (which presumably determines the relative strength of absorption in different lines) may predominate so greatly over all that of all other factors in determining the spectral type.

We may now review rapidly some of the relations which have been brought to light between other characteristics of the stars and their spectral types. First, as regards the relative numbers of stars of the different classes, we have in Table II some results of counts made at Harvard.[8]

TABLE II.

| Spectrum | O | B | A | F | G | K | M | N |
|---|---|---|---|---|---|---|---|---|
| No. above 3.25m. | 3 | 52 | 32 | 16 | 20 | 35 | 21 | 0 |
| ,, 6.25m. | 20 | 696 | 1885 | 720 | 609 | 1719 | 457 | 8 |
| Percentage in Galactic region | 100 | 82 | 66 | 57 | 58 | 56 | 54 | 87 |

Classes A and K make up more than half of all the stars brighter than 6·25 m—that is, of the stars visible to the naked eye. The remaining stars are divided fairly evenly among the other four principal classes, while only one star in 300 is of Class O, and only one in 800 of Class N. The relative proportions of the different classes are, however, different in different parts of the heavens, as is indicated by the last line of the table, which give the percentage of stars of each class which lie in a belt covering one-half of the celestial sphere, and extending for 30° each side of the Milky Way. All the stars of Class O are close to the central line of the Galaxy (except for a few in the Magellanic Clouds). The stars of Class B are very strongly concentrated in the galactic region; those of Class A are considerably so; those of the following classes very little, except in the case of Class N (for which the tabular percentage is derived, not from the eight brightest stars of this class alone, but from a much larger number of fainter ones).[9]

The relative proportions of the different classes vary also with the apparent brightness of the stars. Among the stars brighter than 3·25m., as the table shows, Class B has more representatives than any other; but the percentage of this type steadily diminishes as we pass to fainter stars. The percentage of stars of Class A at first increases with diminishing visual brightness; but there is good reason to believe that, at least in regions remote from the Galaxy, the relative proportion of these too falls off rapidly in the neighbourhood of the ninth magnitude[10]; and Fath's work on the integrated spectrum of the Milky Way[11] shows that, even there, the bulk of the very faint stars which form the galactic clouds must be of Secchi's second type (F, G, or K).

Counts of the stars down to any given magnitude may, however, be very misleading unless we bear in mind the enormous preference which this method of observation gives to the stars of great actual luminosity, which can be seen afar off, and hence are being sought in a much greater volume of space than those of small luminosity. A difference of but five magnitudes in the real brightness of two groups of stars gives the brighter kind (if both are uniformly distributed in space) a thousand-fold better chance of getting into our catalogues; and this example understates the actual conditions in some cases. Mere counts of stars need therefore to be supplemented by such knowledge as we can obtain concerning their distances.

Much information can be obtained from the average proper-motions of the stars of the various classes, and still more by deriving their average parallaxes from the mean parallactic drift due to the motion of the solar system in space. Studies of this character have been made by several investigators of the first rank. Their results, which are summarised in Table III., show certain apparent discrepancies, which, however, arise principally from differences in the methods according to which the various workers have selected the groups of stars for investigation.

TABLE III.

| Spectrum | Mean centennial proper-motion | | | Mean parallax | | | % rej. |
|---|---|---|---|---|---|---|---|
| | Kapteyn | Boss | % rejected | Kapteyn | Boss | Campbell | |
| | ″ | ″ | | ″ | ″ | ″ | |
| O | | 1·6 | 0 | | 0·004 | | |
| B | 2·6 | 2·4 | 0 | 0·007 | 0·007 | 0·006 | 0 |
| A | 5·8 | 4·6 | 3 | 0·010 | 0·010 | 0·016 | 3 |
| F | 14·5 | 7·7 | 28 | 0·022 | 0·012 | 0·035 | 3 |
| G | 27·0 | 5·2 | 20 | | 0·008 | 0·022 | 8 |
| K | 13·0 | 5·7 | 6 | | 0·010 | 0·015 | 9 |
| M | 5·9 | 5·0 | 6 | 0·011 | 0·008 | 0·011 | 3 |
| N | | 3·2 | | 0·0007 | | | |

Kapteyn's data[12] represent the mean proper motions and parallaxes of all the stars of the fifth magnitude of each class, except for Class N, in which, to get enough stars, it was necessary to include faint objects, so that the average magnitude is here 8·3. His results show a conspicuous maximum of average proper-motion and parallax for Class G, with a rapid fall on both sides of it. The stars of Class N would have to be brought about five times nearer to appear as bright as the others, but even then they would have the smallest mean parallax of all.

Boss,[13] in his investigation of the solar motion, had at his disposal very accurate proper-motions of all the stars down to 5·7m., and about half as many more between this and the seventh magnitude. The average magnitude of his stars is therefore nearly the same as that of Kapteyn's. But, for very good reasons, he excluded from his main solution all stars with proper-motions exceeding 20″ per century. The percentage of stars thus excluded (which differs greatly from class to class) is given in the fourth column of Table III. It is natural that this often drastic rejection of the large proper-motions, and hence in general of the nearer stars, should greatly diminish his mean values. Among the classes in which the mean proper-motion is small, the percentage of exclusion is also small, and the results are but little modified. But it is noteworthy that the exclusion of 6 per cent. of the stars of Class K has reduced the mean proper-motion in a greater ratio than that of 28 per cent. of those of Class F, and also that the removal of one-fifth of the stars of Class G decreases the mean for the remainder to less than one-fifth of its initial value. It appears from these results that a large majority of the stars of Classes F, G, and K have nearly, if not quite, as small parallaxes and proper-motions as those of Classes A and M, though they are not quite so remote as the stars of Class B. The large mean values obtained for all the stars of these classes are due to the presence of a relatively small proportion of near and apparently rapidly moving stars, of which the percentage decreases, but the mean proper-motion and parallax increase, from F to K.

---

[7] Abbot, "The Sun," p. 252, 1911.

[8] Harvard Annals, vol. lxiv., p. 134.

[9] Harvard Annals, vol. lxvi., p. 213.

[10] *Astronomical Journal*, vol. xxvi., p. 153, 1910.

[11] *Astrophys. Journal*, vol. xxxvi., pp. 362–367, 1912.

[12] *Astrophys. Journal*, vol. xxx., p. 295 : vol. xxxii., p. 91, 1909–10.

[13] *Astronomical Journal*, vol. xxvi., pp. 187–201, 1911. The mean proper-motions of the few stars of Classes O and N which appear in Boss's Catalogue have been added by the writer.

Campbell's results[14] are derived from a comparison of the radial velocities and proper-motions of nearly 1200 stars, mostly brighter than the fifth magnitude, and averaging about a magnitude brighter than Boss's stars, which would lead us to expect that their mean parallaxes should be 40 or 50 per cent. greater. In his work, "a few stars having proper-motions abnormally large for their classes were omitted in accordance with definitely set limits" (which unfortunately are not described more specifically). The approximate percentage of exclusion is given in the last column of the table. It appears on inspection that the differences between Campbell's and Boss's results for stars of Classes A, K, and M arise mainly from the greater brightness of Campbell's stars; those for Classes F and G are due mainly to the different percentages of exclusion, and that the only significant difference is that Campbell's B stars, though averaging much brighter to the eye than Boss's, have a slightly smaller mean parallax, and therefore must be, on the average, of greater real brightness.

Closely allied with these investigations is the determination of the mean peculiar velocity of the stars of each spectral class. The results of Boss and Campbell, reached almost simultaneously, and from quite independent data—proper-motions in one case and radial velocities in the other—are in extraordinary agreement. The values found for the average component of motion in any arbitrary direction are (in kilometres per second):—

| Spectrum | B | A | F | G | K | M |
|---|---|---|---|---|---|---|
| Campbell | 6·5 | 10·5 | 14·4 | 15·9 | 16·8 | 17·1 |
| Boss | 6·3 | 10·2 | 16·2 | 18·6 | 15·1 | 17·1 |

The rapid increase of the mean velocity from B to F is very remarkable. The slow further gain from F to M would attract little attention if it were not in the same direction.

It should here be added that the phenomenon known as preferential motion, or "star-streaming"—the excess of the average peculiar velocity of the stars in a certain direction above those in the perpendicular directions—is almost absent in Class B, very conspicuous in Class A, and somewhat less so in the following classes, being partially concealed by the greater average magnitude of the velocities.

Another notable difference between the various spectral classes may be found in the number of binary stars, both visual and spectroscopic, among them. We may distinguish two classes of visual double stars; binary stars for which orbits have been computed (with periods rarely exceeding two centuries), and physical pairs, the real connection of which is proved by common proper-motion, but the relative motions of which are slow, and periods long—probably often thousands of years. The counts of the two classes here given are from a list prepared in the course of my work, and include all stars for which the necessary data could be obtained, including many stars for which unpublished observations of spectra have been generously furnished me from Harvard. For the spectroscopic binaries, Campbell's counts have been taken from his catalogue of 1910.[15] They include all the systems the periods of which were then known, and are divided into two groups, one including all the periods of which are less than ten days, and also all those the periods of which, though not exactly known, are described as short; the other all the known periods exceeding ten days, and those which, though not precisely determined, are known to be long.

Table IV.

| Spectrum | Visual binaries | Physical pairs | Spectroscopic binaries | |
|---|---|---|---|---|
| | | | Short period | Long period |
| B | 0 | 52 | 33 | 15 |
| A | 14 | 152 | 15 | 14 |
| F | 33 | 115 | 11 | 9 |
| G | 24 | 74 | 8 | 14 |
| K | 12 | 62 | 0 | 13 |
| M | 0 | 11 | 0 | 2 |

It appears that, in Campbell's picturesque phrase, visual double stars of relatively short period "abhor" Classes B and M, the greatest number being of Class F, with G a good second. Among the physical pairs, of long period, the most favoured class is A. Class B is abundantly represented, and Class M very sparingly.

The percentage of stars which are found to be spectroscopic binaries is very probably greater among Classes B and A than lower down the list. As time goes on, indeed, more and more of the stars of these "later" types are found to be spectroscopically double, but of long period; but among these classes the detection of such systems, where the range of velocity is small, is much easier than among the stars of the first type, the lines of which are diffuse. In any case it is certain that short periods are almost confined to Classes B, A, and F, and are especially abundant in the first of these. The few short-period stars of Class G which appear in the table are all Cepheid variables, most of which were selected for observation on this account, and would not otherwise have got into the list.

Finally, we may note that, among variable stars, those of the eclipsing type, such as Algol or Beta Lyræ, are for the most part of Classes A and B, though there are a number of Classes F and G, and one at least of Class K; that the Cepheid variables are almost all of classes F and G, with a few A's and K's; and that almost all the irregular variables, and all the variables of long period, are of Classes M or N. Stars of Class M the spectra of which show bright hydrogen lines are without exception variable, and almost all the stars of Class N are also subject to changes in brightness.

*(To be continued.)*

## *UNIVERSITY AND EDUCATIONAL INTELLIGENCE.*

Cambridge.—Dr. James Ward, professor of mental philosophy and logic, has been nominated to represent the University on the occasion of the celebration at Oxford on June 10 of the seventh centenary of the birth of Roger Bacon, and Dr. Sorley, Knightbridge professor of moral philosophy, to represent the Univer-

---

[14] Lick Observatory Bulletin, vol. vi., p. 134, 1911.

[15] Lick Observatory Bulletin, vol. vi., p. 38, 1910.